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Comparing how the public perceive CCS across Australia and China

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ABSTRACT

Whilst carbon capture and storage (CCS) has been promoted as a direct countermeasure against global warming, there remains much debate about what its final role as a climate change mitigation strategy will be. One key criticism directed towards CCS has been its inability to gain public support. This study compares public attitudes to the range of low carbon energy sources and technologies across Australia and China, and is the first study to compare primary data across these two countries on this topic. An online survey encompassing a broad set of questions was used to identify the factors that are associated with support for CCS compared to other energy technologies. Data were collected from a nationally representative Australian sample (n = 2383) and from Chinese urban residents across six regions (n = 1266). The survey confirmed low levels of knowledge and support for CCS in both countries. However, male respondents, those who perceived themselves to have higher knowledge of CCS, and those who valued economic outcomes over environmental protection were more likely to support CCS - as long as the risks were not perceived to outweigh the benefits. The results found that for Australians who believed in human-induced climate change they were likely to be unsupportive of CCS. This opposition appears to be linked to no tolerance for extending fossil fuels as in our factor analysis CCS was aligned to fossil fuels in Australia. In both countries, support for renewable energy technologies remains strong. Given the International Energy Agency's future energy demand projections, combined with slow progress towards meeting the Paris Climate Agreement, the lack of knowledge and support for CCS is concerning. While there have been some technological advances, without parallel improvements in public acceptance of CCS, it will be difficult to see any commercial projects going forward in the near future. Although, the Chinese government's success in educating on climate science, as evidenced in these results, suggests that they may be more effective at informing the public of the benefits of CCS and take the lead on its deployment for climate change mitigation. Based on the latest climate models, it is almost crunch time for governments to decide if CCS has a role to play as part of an energy transition to a low carbon future or perhaps it may be time to turn their focus to climate adaptation.

1. Introduction

For the past few decades, carbon capture and storage (CCS)[2] (or carbon capture utilisation and storage (CCUS)) has been promoted as a direct countermeasure against global warming. However, there remains much debate about what its final role as a climate mitigation strategy will be. With the rapid deployment of renewable energy generation technologies, and a growing range of storage options ensuring greater security of supply from these more intermittent energy sources, the necessity for CCS technology in the overall energy mix has been questioned. Deployment of CCS technology has been slow - hindered by criticism based largely on its inability to gain public support, both from financial and safety perspectives. However, CCS proponents argue that most of the broader public remain unaware of CCS and its potential. Therefore, monitoring public attitudes towards CCS remains an important part of the strategy for reducing the uncertainty about the future of CCS.

In response to this, since the early 2000's, a number of large scale surveys have been deployed across various countries to understand public attitudes towards CCS. These have mainly focused on providing information as well as aiming to identify the concerns the public holds about CCS and ways to address these concerns (Ashworth et al., 2013;

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[2] We use CCS to represent both CCS and CCUS in this paper

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de Best-Waldhober et al., 2009; Sharp et al., 2009). However, the lack of growth of commercial projects, combined with a seemingly lagging commitment towards CCS in many countries, means such public attitude studies have occurred less frequently in more recent times. In addition, it has been noted that there have been very few studies comparing public attitudes towards CCS across the developed and developing world (Ashworth et al., 2015). This paper sets out to address these gaps by comparing public attitudes towards CCS, across both Australia and China, using a similar public attitudes questionnaire.

2. Background

2.1. Earlier focus of socio-psychological studies

Throughout the research, development and deployment phases of CCS there has been a range of socio-psychological studies examining a variety of concepts that relate to the public acceptance, or tolerance, of the technology. These have ranged from identifying the factors that might influence levels of support (i.e. levels of knowledge about CCS (Hobman and Ashworth, 2013), the perceived risks and benefits of CCS (L'Orange Seigo et al., 2014), and whether a belief in anthropogenic global warming leads to greater support or opposition for CCS (Dowd et al., 2014; Itaoka et al., 2014)), through to contemplating the best way to communicate about the technology (Brunsting et al., 2011; Koot et al., 2016) and examining factors such as the role that trust (Terwel et al., 2009), values and beliefs play in influencing attitudes and ultimately acceptance (Cherry et al., 2014; Huijts et al., 2007).

2.2. Framework predicting acceptance or tolerance of CCS

One of the more advanced theories that provides a model to identify the causal links between intentions and acceptance is the Technology Acceptance Framework (TAF) (Huijts et al., 2014, 2012). The TAF provides a comprehensive framework which encapsulates many of the factors that have been studied in the earlier CCS acceptance research and other science and technology studies. It combines the well-known theory of planned behaviour (Ajzen, 1991) which proposes that 'attitudes', 'subjective norms' and 'perceived behavioural control' influences acceptance. That is, an individual is more likely to accept a new technology if they evaluate its costs, benefits and risks positively (i.e. attitude), their family and friends have a similar opinion about it (i.e. subjective norms) and they believe they have the ability to control or manage the technology (i.e. perceived behavioural control).

The other theory integrated into the TAF is the norm activation model (Schwartz, 1977; Schwartz and Howard, 1981) which states that personal norms or feelings of moral obligation influence intentions and behaviour. The TAF model proposes two determinants of personal norms. The first is 'problem perception' which refers to the evaluation of the adverse consequences of not acting. For example, the consequences of not using a more environmentally friendly energy source may result in increased air pollution and climate change (Huijts et al., 2014). The second factor is 'outcome efficacy' which is a belief that individual actions can be effectual and they have the potential to contribute to effective solutions to the problem (Huijts et al., 2012). Finally the TAF examines the role of trust in the actors responsible for the technology alongside issues of procedural and distributive fairness. It also acknowledges that knowledge and experience with a technology can influence overall acceptance (Huijts et al., 2012). The TAF forms an important structure for informing this study.

2.3. Public attitude studies in China

Unlike the developed world, to date in China, there have been few studies published in English in peer-reviewed literature examining societal attitudes towards CCS, be it expert (Liang et al., 2011), the general public (Chen et al., 2015; Duan, 2010; Li et al., 2014) or a combination of both (Yang et al., 2016). However these handful of studies have built on the earlier socio-psychological international research which helps to make it useful to compare across countries.

The early surveys were delivered through face to face interviews with pen and paper, with later studies including the addition of online surveys. Face to face interviews were chosen to ensure those with low literacy levels could also participate. In 2009, Duan's sample (N = 534) was from a number of geographical locations across China, whose residents had been holidaying when the survey was deployed in Xiamen, Fujian Province. Chen and colleagues implemented a national survey in 2013 geared towards educated elites across 19 provinces and 2 regions, while in 2014, Yang et al.'s (2016) (N = 349) survey reached across 27 Chinese provinces and regions, although overall representation was low in comparison to the total Chinese population.

Despite the lack of nationally representative samples a common finding across the research is that the majority of the Chinese population agree that climate change is an issue (e.g. 82.4% in Duan, 2010), with much higher agreement than evidenced in many other countries. The researchers claim this is related to the role the Chinese government plays in informing the population about the issue of climate change (Chen et al., 2015). Like many other international studies, Chinese respondents reported higher awareness of solar, wind and nuclear and low knowledge and awareness of CCS across all studies. Regression analyses and descriptive statistics confirmed that knowledge of CCS and its role in CO_2 emissions reduction was significant for CCS acceptance. However, if participants felt the risks posed by CCS were too great, they were unlikely to accept CCS. Chen et al.'s (2015) research further highlights that risks relating to transport and potentially locating storage sites close to individual houses was not tolerated by many, while Yang et al. (2016) found that people living in coal mining regions were more likely to accept CCS, although this was also mediated by projects not being located near to them. In the Duan (2010) model higher education was not a predictor of support for CCS, and while awareness of climate change issues was positively correlated with CCS acceptance it was not significant.

2.4. Research aims

Previous studies in Australia and China have identified a diverse number of factors that may contribute to acceptance of CCS. This research aims to test the generalisability of those factors by comparing responses of regular citizens in Australia and China, in order to examine levels of knowledge of and support for CCS in the general public. Specifically, we asked about preferences for a range of energy technologies, levels of factual and perceived knowledge, perceptions of risks and benefits (for both CCS and solar thermal technology), as well as environmental, economic and cultural orientations.

3. Methods

3.1. Questionnaire design

The questionnaire used built on components of the TAF model and was designed to include questions that would provide a solid basis for identifying key factors associated with public support for CCS and other energy sources. Developed collaboratively across both countries, it was also intended to maintain a level of replicability with previous surveys to monitor changes in the evolution of preferences for different energy technologies. The questionnaire was broadly divided into seven sections.

To ascertain eligibility respondents first answered screening questions (age, gender, and postcode). Section 1 focused on objective and perceived knowledge about energy sources and technologies. Consistent with previous surveys (Jeanneret et al., 2014), participants were then presented with definitions for each of the energy sources and technologies under evaluation, with Section 2 asking participants to

identify the levels of technology support, factors for that support and potential funding priorities.

Additional questions were included to enable international longitudinal comparability including comparisons with previous environmental and energy-related surveys. Section 3 included key questions about trade-offs between economic growth, environmental protection and climate change. Section 4 included questions from Steg et al.'s (2005) scale which measures personal norms and ascriptions of responsibility. Section 5 included questions on individual and household energy behaviours. Most questions in Sections 3 and 5 were adapted from the World Values Survey, which has included similar questions since 1995.

Section 6 of the questionnaire aimed to analyse attitudes and perceptions of CCS compared to renewable energy. Questions in this section were preceded by a short video[3] (Australia) and descriptive text (China) presenting CCS as one technology that, when combined with energy efficiency and renewable energy technologies, can reduce global emissions and thus help to address the issue of climate change. Questions following this video were adapted from (Huijts et al., 2014, 2012) the TAF framework for understanding technology acceptance – in this case CCS and renewable energy projects. Section 7 collected data on individual values (Yoo et al., 2011), and standard sociodemographic information to enable us to characterise our sample and understand different trends between groups. The details of the questions are described in the supplementary materials.

3.2. Data analysis

In Australia, a market research company (Q & A Research) was engaged to collect data via an online survey. Data was collected between June and August 2017 from a nationally representative Australian randomised sample aged 18 years of age and older of 2540 surveys, and of these 2383 were included in the final dataset (95% confidence level and +/-1.76% confidence interval). The geographical distribution of participants per state follows a representative random sampling, corresponding to state population size. In the Chinese sample, a total of 1352 surveys were completed by Chinese urban residents in six regions, and of these, 1266 were included in the final dataset. While the Chinese sample aimed to be broadly representative geographically, there was a focus on examining the attitudes of the general public who were highly educated. This resulted in a higher proportion of both younger and female participants being randomly sampled, in line with population education demographics (Chinese Ministry of Education (MOE, 2017).

Data were cleaned and analysed using Stata/MP v.15.1 (StataCorp LLC). In both the Australian and Chinese datasets, completed surveys were discarded if participants had responded in a biased way, such as 'straightlining', which occurs when respondents 'fail to differentiate between the items with their answers by giving identical (or nearly identical) responses to all items using the same response scale' and can negatively affect both reliability and validity of survey responses (Yan, 2008, p. 521). In addition, completed surveys were discarded from the Australian dataset if completion time was more than 6 h (average completion time was 30 min). Any respondents under 18 years of age were removed from the Chinese dataset.

Descriptive analyses examined respondents' knowledge of key energy issues and different energy technologies. Bivariate analyses (cross tabulations, one-way ANOVA and t-tests) explored relationships between demographic characteristics and knowledge, support for, and perceptions of the risks and benefits of different energy technologies. Perceptions of climate change and environmental attitudes, and preferences for energy cost, reliability and stability were also examined using bivariate analyses. Correlations (Pearson Correlation, *r*) and regression models examined the strength of associations between energy preferences and key variables.

Respondents were also asked to rank 12 energy technologies in the priority order that they would allocate public funds toward their development and implementation. In the Australian survey, this was a forced choice question, i.e. respondents ranked all 12 technologies (no missing responses). However, it was not a forced choice question in the Chinese sample, which resulted in n = 749 where respondents ranked all 12 technologies. (For the remaining n = 517, around 50% ranked 10 or fewer energy technologies.) Only complete responses were included in the results reported in this paper.

3.3. Participant demographics

The Australian sample was comprised of 49% male and 51% female while the Chinese data was comprised of 40% male and 60% female (refer Table 1). The Chinese data was particularly skewed towards the younger population with the mean age being 30 years of age compared to the Australian mean of 47 years. Almost 35% of the Chinese sample identified as full-time students compared with only 5.75% of the Australian sample.

4. Results

4.1. Knowledge and support for energy technologies

When participants were asked to rate their knowledge of the various energy technologies (1 = no knowledge to 7 = expert knowledge), in all instances the Chinese sample were more likely to rate their knowledge higher than the Australian sample. Consistent with earlier studies of the 12 energy sources and technologies, respondents in both countries indicated they had the least level of knowledge about CCS and biomass (AU: CCS, M = 2.5 & biomass, M = 1.9; CH: CCS, M = 3.0 & biomass, M = 3.0). Participants were then provided with simple definitions of each generation source and technology and asked to rate how strongly they agreed or disagreed with these different options for meeting their country's energy needs (1 = strongly disagree to 7 = strongly agree). Across both countries, renewable energy technologies including solar PV, solar thermal, wind, hydroelectricity and wave were the technologies which gained the most support (Table 2). In addition, Chinese respondents expressed more support for nuclear (M = 4.6) and biomass (M = 4.5) when compared to the Australian responses (nuclear M = 3.7; biomass M = 3.6). China is a big agricultural country with a wide range of biomass resources. The Chinese people are familiar with the use of biomass and have a positive attitude towards it. As well as producing clean electricity, biomass energy production alleviates two major environmental problems - the open-field incineration of straw, and accumulation of urban bio-waste. In the process, biomass energy can increase farmers' income. However, the Chinese were less supportive of coal (CH: M = 3.2, AU: M = 3.7). Coal was by far the least preferred energy source in China whereas in Australia coal seam gas was least preferred.

To further test individual preferences towards the energy generation sources, participants were asked to *rank the energy sources/technologies in the priority order you would allocate public funds for their development and implementation* (where 1 = most funding support to 12 = lowest funding support). As shown in Fig. 1, CCS ranked 8 out of the 12 in Australia and 10 out of 12 in China (note reduced sample number). Consistent with earlier surveys, solar energy was ranked number one across both countries (Chen et al., 2015; Duan, 2010; Hobman and Ashworth, 2013), with CSG and coal ranked the lowest in Australia and China respectively. Given the contention surrounding the CSG industry in Australia the low support for CSG is not surprising. Similarly, in more recent years China has focused on eradicating pollution from coal fired power stations. This likely explains the low support for coal in China

[3] https://www.youtube.com/watch?v=aHtbDmzjYgg&list=PL44479250B58056C7

Table 1
Demographic profile of respondents in both countries.

		Australia	China
Gender	Male	48.7%	39.5%
	Female	51.3%	60.5%
Age (years)	Mean (SD)	47.5 (16.8)	30.2 (10.4)
Age Group	18-34	28.9%	68.4%
	35-54	35.4%	30.1%
	55+	35.7%	1.5%
TOTAL		2383	1266

Table 2
Mean support for energy sources/technologies.

	AUSTRALIA		CHINA		
	Mean	(SD)	Mean	(SD)	Difference in means*
Solar (PV)	5.59	(1.36)	5.64	(1.51)	0.403
Solar (thermal)	5.41	(1.37)	5.55	(1.55)	0.008
Wind	5.39	(1.51)	5.59	(1.54)	0.000
Hydroelectric	5.33	(1.31)	5.32	(1.54)	0.828
Wave	5.11	(1.48)	5.22	(1.64)	0.043
Geothermal	4.32	(1.55)	4.85	(1.63)	0.000
Gas	4.15	(1.55)	4.63	(1.68)	0.000
CCS	3.81	(1.56)	4.29	(1.69)	0.000
Coal	3.75	(1.79)	3.23	(1.71)	0.000
Nuclear	3.67	(1.94)	4.63	(1.80)	0.000
Biomass	3.55	(1.56)	4.55	(1.90)	0.000
Coal Seam Gas	3.50	(1.71)	3.52	(1.65)	0.755

* Two sample *t*-test with unequal variances, $p < 0.05$.

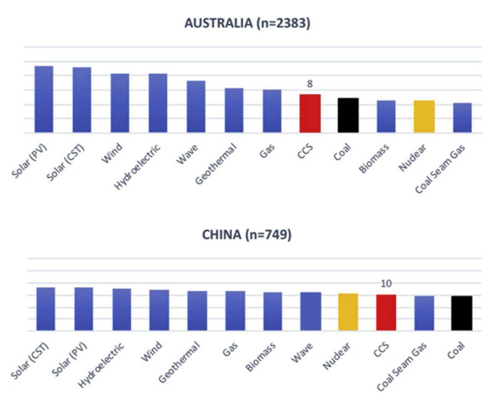

Fig. 1. Comparative rankings of each energy source/technology.

(12th) compared to Australia (9th). On the other hand, higher support for nuclear power perhaps reflects China's successful and expanding deployment of nuclear power plants for baseload power while Australia only has one nuclear research reactor which may account for the low preference in Australia.

In an attempt to uncover the motives that influenced individual preferences, participants were asked to rate a list of factors in terms of how much they considered these factors when deciding whether or not to support new energy sources and related technologies (refer supplementary materials). Linear regression models revealed patterns of associations between these factors and support for CCS. In Australia, support for CCS was positively associated with economic issues (e.g. jobs, skills development) and cost factors ($p < 0.0001$ and $p < 0.01$ respectively), while it was negatively associated with environmental protection (e.g. impact on ecosystems, humans, plants and animals) and climate change ($p < 0.001$). In comparison, in China support for CCS was positively associated with environmental protection and location factors ($p < 0.01$ and $p < 0.1$ respectively). Because of China's vast territory, large population and unbalanced regional development, it is reasonable that people's attitudes toward CCS also vary from region to region, with those in coal mining regions being more supportive.

4.2. Comparing the advantages, risks and benefits of CCS and renewable energy

The short video (Australia) and descriptive text (China) discussed the roles of CCS, renewable energy and energy efficiency as options for mitigating CO_2. Following Slovic's (1987) risk research examining trade-offs for nuclear support, participants were asked to respond whether they felt *the advantages outweigh the risks as a carbon reduction option* for both CCS and renewable energy. The two questions were randomised to prevent order bias. A higher percentage of the Chinese sample rated advantages over risks for CCS (Adv:56%, R:19%) when compared to the Australian sample (Adv:45%, R:16.5%). However, Australia had a larger portion that responded neither (AU:14%, CH: 7%) or did not know (AU: 24%, CH:18%) compared to the Chinese sample (see Fig. 2). While these results demonstrates some tolerance for CCS, based on the larger percentage in Australia who are ambivalent or don't know, it is unlikely that people will embrace CCS in their backyard without some additional benefits which are to date yet to be defined.

This tendency for more Chinese to rate advantages over risks was also observed for renewable energy (see Fig. 3). However, in both country samples, the percentage agreeing there were more advantages (CH:75%, AU:67%) than risks (CH:14%, AU:9%) was much higher. There was also less uncertainty associated with renewable energy in the Chinese sample compared to Australia. In China, the environmental condition in many areas is very poor, so people in those areas are eager to introduce new technologies that would contribute to improving environmental conditions. It is therefore likely that, compared with the Australian public, Chinese people will be more willing to accept new 'cleaner' technologies such as CCS or solar energy.

Participants were then asked a variety of questions about how likely (1 = very unlikely to 7 = very likely) they felt a range of risk and benefit consequences associated with CCS and renewable energy were to occur. For CCS, the highest perceived benefit for the Chinese sample was a decrease in the dependency of energy supply from other countries (M = 4.95). This may be related to the successful application of CCS Enhanced Oil Recovery (CCS-EOR) technology in China,which will not only reduce CO_2 emissions but also improve domestic oil production which can reduce China's dependency on importing energy (China National Petroleum Corporation (CNPC, 2018; Global CCS Institute,

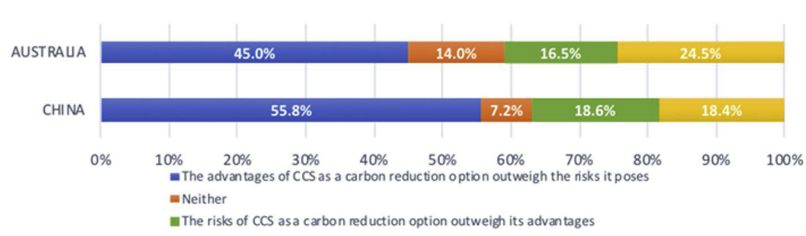

Fig. 2. Advantages versus risks of CCS.

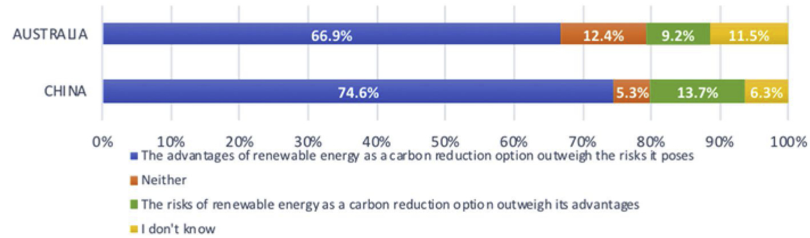

Fig. 3. Advantages versus risks of renewable energy.

2018). While for the Australian sample it was to decrease CO_2 emissions (AU: M = 4.83) (see Table 3). This was also rated the second highest benefit for the Chinese sample (M = 4.83). Both the Australian and Chinese samples perceived the most likely potential risk to be in the transport of CO_2 in pipelines (AU: M = 4.37; CH: M = 4.48). This is consistent with Chen et al.'s (2015) findings where a major risk was related to transporting CO_2 in pipelines.

Table 3
Means of perceived risks and benefits of CCS.

CCS risks	AUSTRALIA		CHINA	
	Mean	(SD)	Mean	(SD)
Risk of a major accident	3.89	(1.49)	4.10	(1.68)
Risk for future generations	4.07	(1.53)	4.23	(1.49)
Environmental risks	4.01	(1.56)	3.98	(1.63)
Health risks for host community	4.03	(1.54)	4.38	(1.58)
Risks in CO_2 storage	4.31	(1.53)	4.39	(1.49)
Risks in CO_2 transport	4.37	(1.49)	4.47	(1.53)
Risks increase fossil fuels	4.08	(1.56)	4.16	(1.65)
CCS benefits	**AUSTRALIA**		**CHINA**	
	Mean	(SD)	Mean	(SD)
Increase economic growth	4.40	(1.27)	4.76	(1.54)
Decrease in climate change	4.48	(1.46)	4.78	(1.48)
Increase employment	4.51	(1.28)	4.59	(1.45)
Increase energy efficiency	4.11	(1.57)	4.70	(1.50)
Decrease CO_2 emissions	4.83	(1.46)	4.83	(1.57)
Decrease dependency on other countries	4.45	(1.45)	4.96	(1.51)

4.3. Perceptions of climate change

Prior research suggests that for CCS to be accepted it will be important to link it to the need for climate change mitigation. It was clear the majority (83.3%) of those in the Chinese sample were more convinced that global warming was already happening compared to the Australian sample (68.6%) (Fig. 4). While in both samples about 9% felt global warming would start happening in the next 30 years, 11% of Australians did not think global warming was happening and won't, compared with only 1.6% of the Chinese. Similarly there were more Australians (11.5%) who did not know or who were not sure whether global warming was happening or would happen compared to only 6.6% of the Chinese sample. The majority in both countries (AU: 45%; CH: 58%) attributed the causes of climate change to be from a combination of natural changes in the environment as well as human activity.

4.4. Support variables - factor analysis

Factor analyses with promax rotation were conducted on the 12 support variables to identify any differences between the two countries. Each country's sample loaded on two factors and followed an overall similar pattern, with slight variations. In the Australian sample, geothermal did not load on either factor, while in the Chinese sample, biomass, nuclear and CCS did not load on either factor. Only items with factor loadings above 0.7 and communalities above 0.5 were retained and used to create two indices for each country, as shown below. Such measures may be used as a proxy of public support for energy sources and technologies funding and investment. The analyses show there is support for both fossil fuels and renewable energy however the Chinese sample were much stronger in their support for renewable energy compared with fossil fuels (Table 4). The factor analysis also shows that in Australia, CCS technology is aligned with fossil fuels. In China however, CCS is neither aligned with fossil fuels nor renewables but is seen more as a technology that can help address climate change and therefore not so heavily aligned with either type of technology.

Table 4
Factor loading matrix, after promax rotation, by country.

	AUSTRALIA (n = 2383)		CHINA (n = 1266)	
	Component			
Energy technology	*Fossil fuels*	*Renewables*	*Fossil fuels*	*Renewables*
Biomass				
Coal	0.864		0.836	
Coal Seam Gas	0.861		0.872	
Gas	0.853		0.734	
CCS	0.849			
Geothermal				
Hydroelectric				0.761
Nuclear				
Solar (thermal)		0.877		0.881
Solar (PV)		0.897		0.882
Wave		0.837		0.816
Wind		0.865		0.880
Variance (proportion.)	73.41%	75.54%	66.59%	71.49%
Cronbach's Alpha	.878	.890	.746	.899

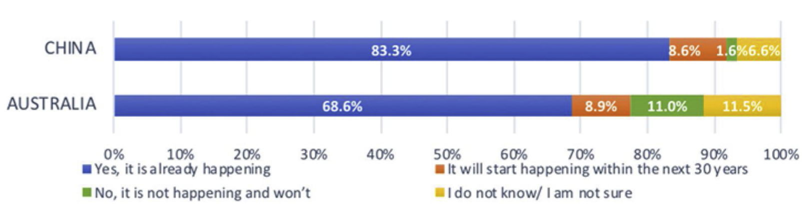

Fig. 4. Agreement with climate change.

4.5. Regression analyses CCS

Regression analyses were used to show the influence of a range of independent variables on public support for CCS (Table 5; for the full list of variables and indices, and Variance Inflation Factors, refer SM2 & SM3). Across both countries participants who believe they have a good understanding of CCS are more likely to support it ($p < 0.001$). In keeping with perceived knowledge, the coefficients suggest that in both countries those who are males and more highly educated are more likely to support CCS. Similarly, those who perceive the social, economic and environmental benefits of CCS to outweigh any risks are also more likely to be supportive of it.

The model suggests that in Australia those who prioritise longer term outcomes over the shorter term, economic growth over the environment, and trust government and the CCS industry to act in the best interests of society, are more likely to support CCS. The trust in government question was not asked in China but those Chinese who trusted the CCS industry, prioritise longer term outcomes and are concerned for the collective good over individuals are more likely to support CCS. Conversely, Australians who agree that global warming is happening (or will happen in the near future) ($p < 0.001$) and that human activities have contributed to global warming ($p < 0.01$) are less likely to support CCS. Related to this, those Australians who feel some personal or moral responsibility for contributing to energy problems and their solutions do not tend to support CCS.

Comparing the two models it appears that overall the Chinese sample have less strong opinions about CCS, likely related to their perceived lack of knowledge. However, in China feelings of personal obligations towards energy problems indicate support for CCS. Because of the skewed Chinese sample, to test the comparison more rigorously, regression analyses were undertaken on the 35–54 years (SM4.) which confirmed the influence of feelings of personal obligations on support ($p < 0.05$).

4.6. Regression analyses solar thermal

To continue the comparison a regression was run to test the model on support for solar thermal (Table 6). Again, across both countries, self-rated knowledge ($p < 0.001$) of the technology and perceived benefits led to support for solar thermal. Reflecting on the model it appears that while beliefs in global warming were a strong driver for opposition to CCS they are not a strong driver for support for solar thermal. Instead it is driven more by personal norms and values and those who prioritise longer term outcomes over the shorter term. In Australia, support for solar thermal was characterised by trust in the solar industry but not trust in government. It seems that in Australia, those who are supportive of solar thermal do not have faith in the government to run fair and transparent decision making processes around the deployment of solar projects.

5. Discussion

The results from this research confirmed a number of the proposed hypotheses (see Appendices). Across both countries renewable energy technologies have greater support when compared with fossil fuel sources and nuclear energy. With low levels of perceived knowledge, CCS remains an enigma to the majority of people and a comparison with previous surveys shows this has not changed substantially over time (Ashworth et al., 2015; Sharp et al., 2009). Reiner's 2013 survey of the UK found that while awareness of CCS had increased from 5% to 20% in 2013, knowledge of what CCS does was poor (Reiner, 2014). Widespread lack of knowledge about CCS technology can most likely be attributed to the slow progress of multiple commercial scale CCS projects anywhere in the world, with most projects still in an experimental stage of development. Evidence of the converse, where awareness was much higher, albeit negative, is best reflected in the results of a survey of local residents near the cancelled Barendrecht project in the

Table 5
Support for CCS – full samples.

	AUSTRALIA			CHINA		
	B	*SE B*	β	*B*	*SE B*	β
Gender	−0.112	(0.062)	−0.036	−0.132	(0.101)	−0.038
Age	0.004^{*}	(0.002)	0.049^{*}	−0.004	(0.005)	−0.023
Education level [a]						
Level 1	0.000	(.)	0.000	0.000	(.)	0.000
Level 2	−0.007	(0.106)	−0.002	0.186	(0.229)	0.034
Level 3	−0.030	(0.090)	−0.009	–	–	–
Level 4	0.113	(0.100)	0.030	0.114	(0.194)	0.030
Level 5	0.099	(0.113)	0.021	0.351	(0.239)	0.060
Self-rated knowledge: gas or coal with Carbon Capture and Storage	0.153^{***}	(0.021)	0.153^{***}	0.109^{***}	(0.030)	0.107^{***}
Global warming is happening (yes)	-0.397^{***}	(0.075)	-0.119^{***}	0.101	(0.131)	0.022
Humans cause global warming (yes)	-0.180^{**}	(0.068)	-0.056^{**}	−0.028	(0.102)	−0.008
Ascription of responsibility (AR)	-0.075^{**}	(0.027)	-0.078^{**}	0.030	(0.048)	0.026
Personal norms (PN)	−0.010	(0.028)	−0.009	0.084	(0.054)	0.068
Long-term orientation (individual)	0.102^{**}	(0.034)	0.064^{**}	0.074	(0.056)	0.049
Collectivism (individual)	−0.049	(0.028)	−0.039	0.042	(0.044)	0.034
Top priority- economic growth	0.480^{***}	(0.072)	0.143^{***}	0.039	(0.126)	0.009
CCS – Perceived Risks	−0.014	(0.024)	−0.012	−0.000	(0.041)	0.000
CCS – Perceived Benefits	0.128^{***}	(0.035)	0.095^{***}	0.113^{*}	(0.054)	0.076^{*}
CCS - Trust in government (AU only)	0.174^{***}	(0.038)	0.124^{***}	–	–	–
CCS - Trust in industry	0.093^{*}	(0.044)	0.062^{*}	0.048	(0.080)	0.022
CCS - Fairness & transparency of decision-making process	0.091*	(0.040)	0.057^{*}	−0.035	(0.057)	−0.021
Constant	1.615^{***}	(0.293)	.	2.193^{***}	(0.470)	.
Observations	2370			1251		
R^2	0.181			0.056		
Adjusted R^2	0.175			0.043		

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Table 6
Support for solar (thermal) – full samples.

	AUSTRALIA			CHINA		
	B	*SE B*	β	*B*	*SE B*	β
Gender	−0.043	(0.051)	−0.016	0.019	(0.084)	0.006
Age	−0.000	(0.002)	−0.005	−0.003	(0.004)	−0.019
Education level [a]						
Level 1	0.000	(.)	0.000	0.000	(.)	0.000
Level 2	−0.096	(0.089)	−0.026	−0.091	(0.190)	−0.018
Level 3	−0.082	(0.076)	−0.028	–	–	–
Level 4	−0.053	(0.085)	−0.016	0.253	(0.160)	0.072
Level 5	−0.007	(0.095)	−0.002	0.314	(0.198)	0.059
Self-rated knowledge: solar (thermal)	0.151***	(0.017)	0.171***	0.194***	(0.025)	0.207***
Global warming is happening (yes)	0.079	(0.064)	0.027	0.271*	(0.108)	0.065*
Humans cause global warming (yes)	−0.002	(0.058)	0.001	−0.022	(0.085)	−0.007
Ascription of responsibility (AR)	−0.012	(0.023)	−0.015	0.042	(0.040)	0.040
Personal norms (PN)	0.154***	(0.024)	0.168***	0.133**	(0.045)	0.117**
Long-term orientation (individual)	0.132***	(0.028)	0.094***	0.227***	(0.047)	0.165***
Collectivism (individual)	−0.043	(0.024)	−0.039	−0.032	(0.037)	−0.028
Top priority - economic growth	−0.167**	(0.061)	−0.056**	−0.077	(0.105)	−0.019
Renewables - Perceived Risks	−0.070***	(0.019)	−0.076***	−0.059*	(0.030)	−0.052*
Renewables - Perceived Benefits	0.259***	(0.030)	0.228***	0.180***	(0.044)	0.135***
Renewables - Trust in government (AU only)	−0.069*	(0.029)	−0.056*	–	–	–
Renewables - Trust in industry	0.096**	(0.034)	0.072**	0.055	(0.064)	0.028
Renewables - Fairness & transparency of decision-making process	−0.086*	(0.034)	−0.059*	−0.033	(0.048)	−0.021
Constant	2.998***	(0.234)	.	1.651***	(0.360)	.
Observations	2370			1251		
R^2	0.248			0.232		
Adjusted R^2	0.242			0.221		

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

[a]

Education level	Australia	China
Level 1	Up to Year 11 or equivalent	Junior Middle School
Level 2	Year 12 or equivalent	Senior Middle School
Level 3	TAFE/Technical Certificate/Diploma	
Level 4	Bachelor degree	Undergraduate/Specialist
Level 5	Postgraduate qualification	Master or above

Netherlands (Terwel et al., 2012). Responses from the Chinese sample show very low tolerance for coal-fired energy. Coal was ranked last in relation to preferences for where funding should be directed (Fig. 1). Non-acceptance of coal is most likely associated with the excessive levels of pollution experienced in some regions of the country for many years, and the recent focus by the Chinese government to raise public awareness of environmental issues and care. As it stands, the ability to extend the social license of coal-fired power stations through the use of CCS in China is unlikely unless there is a massive education drive by the government, similar to what they have already done with disseminating the science of climate change.

In Australia, the situation is quite different, but also reflects locally specific environmental issues. The least preferred technology was coal seam gas (CSG) or coal bed methane as it is often referred to elsewhere, with coal ranking 9 out of 12 (Fig. 1). The initial roll out of the CSG industry in Australia was very contentious in that it happened quickly, with little purposeful regulation in place. CSG development caught local and global media attention, with a strong focus on conflicts between local landholders and CSG companies over access to land and resources. In addition, public concerns around the use of hydraulic fracturing resulted in a number of moratoria being put in place across many states and territories, at least while scientific inquiries were conducted. While there are now many examples of CSG companies peacefully co-existing with farmers, there remain a number of regional locations in Australia that are strongly opposed to the CSG industry and many people in the cities remain opposed to the practice of hydraulic fracturing.

Australia's relationship to coal is different to China's in that, not only has coal been a mainstay for baseload power supply for many years, but also a major export commodity. Neither does Australia have the chronic air pollution issues faced in China. While the survey shows that those who value the environment are generally opposed to coal, like in China, people living in coal-based regions recognise the importance of coal for their local economy and personal livelihoods (Nisa et al., 2018). This was highlighted more recently with the closure of the Hazelwood coal-fired power station in Gippsland, Victoria. The impacts of this are still being felt but has been evidenced by the closure of a number of services, forcing locals to travel further to purchase basic goods. On top of this, Australia has experienced massive increases in energy prices (both electricity and gas) (Australian Competition and Consumer Commission (ACCC, 2018) and issues of energy supply and affordability have gained political attention and influence. This has resulted in a largely polarized debate around renewable energy generation versus baseload coal-fired power (with a mix of other energy sources) playing out across all forms of media and political and environmental activism. While Australians continue to demand cheaper electricity prices, and in the absence of any fixed price on carbon, it is unlikely that CCS technology will be tolerated to extend the life of coal as part of the transition to a more sustainable energy supply. This is particularly evident with those living in cities and urban areas in Australia. As reported in this paper, low levels of awareness of CCS with the general public means they have no idea of the potential that CCS can play in assisting the just transition to a low carbon economy.

However, the more recent discussions around the emergent hydrogen economy and opportunities for export that include production from fossil fuels with CCS perspectives may start to change. Regardless though it will require much more communication about what CCS and the potential it provides.

While it was expected that those who value the environment over economic growth would not be supportive of CCS, these results also confirm that those who are concerned about climate change do not currently support CCS as a negative emissions technology as part of the solution for climate change. It appears for this group CCS is heavily associated with the extension of fossil fuels which for many who are concerned about climate change extending their use in any way is intolerable. Such results are alarming, particularly for industries such as coal, steel, fertilisers, etcetera, that are relying on CCS technologies to reduce their carbon emissions. More so, the International Energy Agency's (IEA's) models (i.e. 2 °C Scenario (2DS) and the Beyond 2 °C Scenario (B2DS)) clearly identify that for effective carbon mitigation to stay below a two degrees Celsius temperature rise, 'a renewed emphasis on CCS in long-term climate strategies and targeted support for project deployment are vital' (International Energy Agency (IEA, 2017, p. 34). This has been particularly recognised for many of the industrial processes where there are limited substitutes for CCS from very carbon intensive industries (International Energy Agency (IEA, 2016, p. 15) However, there are some environmental activist groups who do support CCS because they are concerned about the absence of action to address the problem of climate change across the world. Such groups take a pragmatic, solutions-oriented approach and consider CCS, under the right regulatory framework, a critical climate change mitigation tool given the world's current and projects reliance on fossil fuels (Smith, 2014). They may view CCS industry proponents as much a part of the problem as a solution, but recognise that they have necessary expertise and knowledge in their field, and are important allies in political processes (Bellona, 2019). Perhaps ironically, CCS industry proponents will need to make these groups a critical friend if they are going to change the image of CCS technology away from 'propping up' coal, to one of being a necessary negative emissions technology with an important role in climate change mitigation. This approach was highlighted in early work from ter Mors who showed that partnering with NGO's can add credibility and build trust in industry proponents connected to CCS (Ter Mors et al., 2010).

Many of the constructs proposed by Huijts et al.'s (2012) TAF were evidenced in these results although there were differences between preferences for the different technologies and between countries. The low explanatory power of the models, particularly in China for CCS suggests that there are other latent variables that have not been included and this requires more work, including a larger focus on Hofstede's cultural scales rather than the abridged version which was included in this questionnaire (Yoo et al., 2011). It might also be that in the Chinese sample, there are no real differences in support for CCS in relation to gender, age, education or beliefs about climate change but that support for CCS is more uniform across the population than in Australia, where clear patterns can be seen in support for CCS in the older age brackets, males, and those who believe global warming is happening.

5.1. Limitations

A limitation to this research was that the Chinese sample was not statistically representative of the whole population (with a skew toward highly educated and younger people, the result of both the sampling strategy and being an online survey) and in some questions the sample size was reduced, due to missing data. Additionally, we recognise that the differences in the sampling strategies and the resultant samples, and the differences in the way information was presented, i.e. a video in the Australian survey and written text in the Chinese survey, limit the comparability of the results. However, where possible we were able to test the robustness of results by comparing the 35–54 years' sample which were of a similar percentage size within the total data set. While this analysis does not then account for age differences in the Chinese responses it provides greater comfort in the significance of findings in the regression analyses. More work needs to be done to understand whether delivering a survey through face to face and paper and pencil changes the responses more widely than using the internet. While this is a much more expensive way to collect the data it would be worth controlling for this across a representative sample, even in one or two provinces or regions to see if it does affect results. Similarly to ensure greater representation of older Chinese participants would inform current understanding of attitudes in that cohort.

It is also recognised that the regression model only explained a small amount of variance in both the full sample (CCS – AU 0.181; CH 0.056; Solar – AU 0.248; CH 0.232) and the 35–54 year model (CCS – AU 0.139; CH 0.089; Solar – AU 0.292; CH 0.202) and there was less significance across the board in the China models. Although, it was stronger in the solar sample which suggests the independent variables are a better fit for technologies that are supported more widely and have less uncertainty around them. Similarly, we aimed to survey attitudes across the range of technologies. A focused survey solely on CCS may return a larger explanatory variance as it would help participants to become stronger in their convictions about the technology – if only in the shorter term.

6. Conclusion

Despite these two countries having completely different structures of government, it appears that across both countries, the general public's responses to CCS are similar. Although, some underlying motivations still require further investigation in both countries, particularly China. Similar findings around support for CCS have been highlighted in earlier comparative surveys, but have never been combined and compared across developed and developing countries such as Australia and China. Individuals in either country will clearly not tolerate CCS if the risks are thought to be too great and there are no obvious social, economic or environmental benefits. As proximity to projects has also shown to be a factor influencing support, this is particularly important for local communities where CCS projects are being considered. In accordance with the recommendations from earlier CCS social science research, early interaction and engagement with those host communities will be critical (Ashworth et al., 2012; Ashworth et al., 2015). Including using strategies such as local community reference groups, shop fronts and local drop in centres to keep everyone across host communities informed as a project develops.

What is clear from this study is that if CCS is to be part of the portfolio of energy and/or climate mitigation options there is much more work required to build a positive business case for the technology. As the price of renewable energy technologies combined with storage reduces, the value proposition for CCS becomes even harder to make. Particularly so when coupled with the ongoing fossil fuel divestment movement that has emerged from individuals and groups with strong pro-environmental values.

China however, is making strong progress across all components of CCS in the technical space. The positive results the Chinese government has seen with educating the public about the science of climate change could be replicated in educating the public about the economic and environmental trade-offs involved in each of the low carbon mitigation options. If this can be done successfully, and there is proof through demonstrations that the benefits of CCS will outweigh the risks, then there is a chance that China may lead the world in CCS deployment. This means it will be important to find opportunities to engage with and educate potential host communities in China as projects move forward, as well as the more influential stakeholders and decision makers.

Clearly support for CCS will not be built on the grounds of environmental issues alone. Rather, support is likely to grow where CCS can allow continued economic growth, provide and ensure the safety of jobs, reduce pollution for improved public health outcomes, and still reduce the impact on the environment and CO_2 emissions without impacting the price of electricity more broadly. This will require very

nuanced communication and engagement activities. Testing messages that focus on the outcomes beyond climate change would be beneficial. Alternatively, if it is unlikely that projects will be moving forward it may be time to reconsider the value proposition for CCS entirely in the developed world. However, with current renewable energy supplies insufficient to fulfil baseload requirements for the imminent future, those working in climate policy should be concerned. Not progressing with CCS technology also places more pressure on the renewable energy and storage industry to find greater efficiencies, rapidly, and at lower cost. Without this it may be time to turn attention to adaptation.

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Appendix A. Supplementary data

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